Draft Conceptual Design Report

Prepared for

Kaiser-Hill

State Highway 93 and Cactus
Rocky Flats, Colorado 80007

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CH2MHILL

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Project Purpose and General Background

The Rocky Flats Environmental Technology Site (RFETS, shown on Figure 1) was previously operated by the U.S. government as a nuclear weapons research, development, and production facility. As part of its Rocky Flats Closure Project, Kaiser-Hill and their subcontractors are assisting the Department of Energy in seeking cost-effective solutions to a variety of challenges associated with closure.

Leaking, but now sealed, solar evaporation ponds at the site have resulted in a plume of groundwater enriched with nitrate and uranium, moving north-northeastward from the ponds along the North and South Walnut Creek watersheds. Portions of this Solar Ponds Plume (SPP) that exceed 100 milligrams per liter (mg/L) nitrate nitrogen underlie approximately 30 acres as shown on Figures 1 and 2.

An existing Interceptor Trench System (ITS) extracts water from the SPP. A network of about 2 miles of gravel-filled trenches cut through much of the SPP's path within the layer of alluvium and colluvium overlying bedrock. Slotted pipe in the bottom of the trenches collects groundwater that is pumped to three 500,000-gallon modular storage tanks (MSTs), and then to an evaporator. Evaporite "saltcrete" is produced at the evaporator and disposed of in a Class 1 landfill.

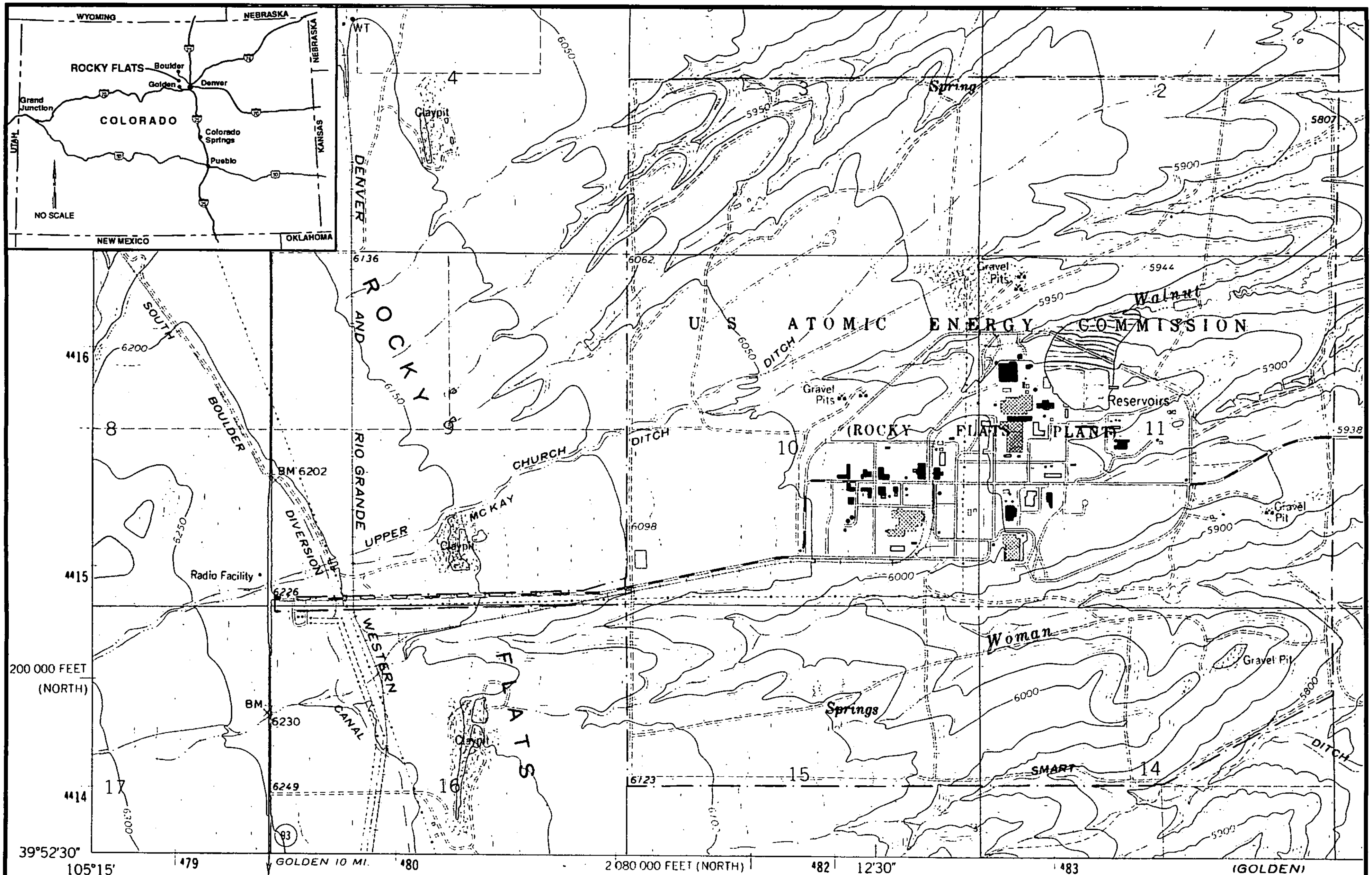
Under Kaiser-Hill subcontract number KH602761MW-040, CH2M HILL (a Kaiser-Hill affiliate), is preparing a conceptual design for passive phytoremediation of the SPP. The purpose of this memorandum is to present the conceptual design for this system, including the following:

- Project Purpose and General Background
- Detailed Project Background
- General Project Concept
- Site Description and Project Delineation
- Conceptual Design
- Summary and Recommendation
- References

Detailed Project Background

The original phytoremediation concept combined passive and active systems (April 9, 1997, memorandum from John Dickey and Alicia Lanier, *Draft Project Concept*; also Appendix B of February 4, 1998, memo from John Dickey and Jim Jordahl, *Solar Ponds Plume Conceptual Design, Task 3: Preliminary Design Parameters.*

The passive system was designed to rely primarily on direct interception by plant roots of SPP water in and slightly above the aquifer. In the passive system, irrigation would occur to promote plant community establishment and then be greatly diminished or discontinued.



Source:
USGS Louisville Quadrangle,
7.5 Minute Series, Photorevised 1971

2484_01 (7/17/98)

LEGEND

SOLAR PONDS PLUME

0 1,000 2,000 FEET
SCALE IS APPROXIMATE

FIGURE 1
ROCKY FLATS SITE LOCATION MAP
U.S. DEPARTMENT OF ENERGY
ROCKY FLATS ENVIRONMENTAL TECHNOLOTY SITE
GOLDEN, COLORADO

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The active system would use water collected from the ITS for irrigation of additional planted areas:

- Within the SPP where groundwater is too deep for direct uptake of groundwater, or
- Outside of the SPP area

Supplemental water would be required in an active system outside of the plume. This is because irrigation outside of the plume, with exclusively nitrogenous water collected in the ITS, would overload the plant and soil system's capacity for conversion and beneficial use of nitrogen, and expand the SPP. However, if nitrogen and water application were limited to amounts that the plants can take up, overload would not occur. Put another way, partial irrigation with SPP water would supply the nitrogen needs of the plants, and additional fresh (low nitrogen) water would be required for maximum nitrogen utilization and plant productivity. The proposed "freshwater" source is highly treated water from the RFETS wastewater treatment plant.

The combined system would provide a solution to multiple water quality problems at the site, including plume containment and treatment, landfill leachate treatment, and zero-discharge from the A-1 and B-1 ponds, respectively, in North and South Walnut Creeks. The layout and vegetation for the active and passive systems would be selected according to remediation requirements and habitat needs of the Prebles mouse and other wildlife in the area.

Before and after the subcontract was let modifications to the original concept were required by changes in site conditions and performance criteria. Some of these changes include the following:

- **Passivity.** A system requiring minimum maintenance was essential. Long-term operation and maintenance of an irrigation system was not acceptable.

- **Application of contaminated water outside of the SPP boundaries** was not acceptable. Therefore, this subcontract originally dealt exclusively with a passive system, irrigated only within the plume boundaries. However, Kaiser-Hill has requested that an active phytoremediation component be described in this memo.

- **Prebles Jumping Mouse Habitat.** The Prebles mouse is listed under the Endangered Species Act. Areas of known or suitable habitat could not be included within the phytoremediation system. The original concept included these areas, assuming that Prebles habitat requirements would be designed into the phytoremediation system.

- It was discovered that the **slope beneath the MSTs was unstable** and that the MSTs were beginning to slip downhill. Finding an alternative to the current SPP management and remediation system is imperative; a system that requires several years to significantly influence the SPP is no longer acceptable.

- The ITS is expensive to operate and does not completely intercept groundwater flow to Walnut Creek. Because of this and MST instability, site managers would like to **retire the ITS and MSTs** as soon as possible.

- The regulatory interpretation of **stream standards** for nitrate-nitrogen and uranium were **moved from the stream to the adjacent groundwater**.

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The changes in regulatory criteria and remediation schedule combined to indicate that passive phytoremediation alone could no longer meet remediation goals. It was recognized that, to meet remediation goals, passive phytoremediation would need to be combined with other technologies, such as reactive walls to remove radionuclides, accelerated denitrification through the addition of carbon to the groundwater, or active phytoremediation.

On July 7, 1998, CH2M HILL was directed by Kaiser-Hill to terminate current work and to provide a summary of progress to date on both the passive and passive/active systems. This document provides a brief overview of the conceptual design of passive and active phytoremediation systems, in the context of current site conditions, constraints, and remediation plans.

Two complementary technologies currently under discussion for the SPP are a reactive wall to remove uranium from groundwater, and a denitrification wall (with barrier walls to channel groundwater) in which added carbon would hasten natural denitrification. These technologies influence the way that phytoremediation fits into the site as follows:

- Under this contract, risks associated with uranium contamination and the phytoremediation system were evaluated at a preliminary level. Due to the soil- and plant-specific nature of uranium mobility, we recommended that irrigation with SPP water be subsurface, and then pilot tested and closely monitored. If uranium levels in plants are at levels that pose unacceptable risk, then future pilot and full-scale irrigation should be with treated wastewater or SPP water after removal of uranium. Operation of a reactive barrier system upgradient of the ITS and the phytoremediation systems resolves these questions.
- While the passive phytoremediation system will remove a significant nitrogen load, its size is constrained by the dimensions of the plume. The passive system cannot be increased further, even to provide needed capacity for beneficial use of SPP nitrogen. This system will treat a significant nitrogen load during its first year by taking up and transforming nitrogen in irrigated SPP water from the ITS, and will increase in capacity as deep roots gain access to groundwater along the capillary fringe. Especially during establishment, complementary technologies like a denitrification wall provide redundancy and reliability. Likewise, phytoremediation provides redundancy where the denitrification wall technology does not conform to site remediation goals. Two of these instances include the following:
  - To consistently accommodate widely varying groundwater velocities with adequate residence time, the wall would have to be unacceptably thick. If the constructed thickness does not accommodate peak groundwater flow rates, periodic breakthrough is likely. The passive phytoremediation system would provide critical redundancy during these episodes, and polish water quality when conditions favor acceptable performance by the denitrification wall.
  - Carbon in the denitrification wall would be gradually consumed, and require periodic replenishment, including significant site disturbance along the length and width of the wall. Over time, the carbon addition by cottonwood in its root zone would reduce or eliminate the need for ongoing maintenance of the denitrification wall.

There are significant advantages to implementing a complex of passive, or nearly passive, technologies to reliably achieve regulatory standards in the SPP area. As a part of this

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complex, passive and active phytoremediation can cost-effectively contribute to the near- and long-term remediation goals.

General Project Concept

The passive system that fits within current project objectives and the potential combined passive/active system are described below.

Passive System

The revised vision for the project is the use of a primarily passive system to be integrated with other remediation technologies such as barrier and denitrification walls. The phyto-remediation system will most likely be used to provide a level of redundancy, reliability, and polishing for nitrate removal. Subsurface drip irrigation will be used only to assist with site establishment during the first 3 years. Groundwater from the ITS and reclaimed water from the wastewater treatment plant (WWTP) will be used for irrigation. Irrigation using the groundwater will provide some immediate removal of nitrate from the system through plant uptake and accumulation of soil organic nitrogen. Retirement of the irrigation system over time will allow the system to self-size as some trees die. Trees that can access the alluvial groundwater will be more likely to survive without irrigation.

Source control and remediation efforts will significantly change the plume over time. The site will be adaptively managed after implementation, based on monitoring of component systems and of the entire plume and watershed. The system is sized maximally within the footprint of the plume and will be installed and operated to avoid conflict with other component systems.

Native, Rio Grande and Narrow-Leafed Cottonwood trees (*Populus fremontii* and *angustifolia*), will be used in combination with adapted grasses. Cottonwood will be used because of their capacity for deep rooting and ability to grow and root under wet conditions (as a phreatophytic, or water loving tree). A grass understory will be established along with the trees in what is known as a relay intercropping system. Grasses will be used to encourage deep rooting of the trees by depleting water near the soil surface and to provide rapid elimination of shallow seeps. As the trees develop a canopy, shading will reduce the grass cover.

The phytoremediation system is expected to provide a significant amount of carbon to the alluvial aquifer that will result in increased denitrification. Over time, it may reduce the need to replace organic amendments if the denitrification wall system is implemented. Preliminary calculations suggest that by year 5, the stand of cottonwood trees could provide an input of over 1,800 pounds per acre per year (lb/ac/yr) of carbon to the soil in the form of root turnover and root exudates. Although an unknown fraction will be either lost as carbon dioxide (CO_2) before reaching the aquifer (because of degradation by aerobic micro-organisms) or through the accumulation of organic matter in the soil above the aquifer, a significant input of soluble carbon to the aquifer would still be expected. Soluble carbon released by plants will be much more bioavailable to denitrifying microorganisms and, therefore, more effective in promoting nitrogen loss through denitrification than the sawdust carbon (primarily cellulose and lignin) typically used in denitrification trench systems.

Passive/Active System

The passive system could be supplemented very effectively by the inclusion of an active component. The active component would provide a means of handling the ITS flow, leaving the capacity of other components to deal with groundwater not removed in the ITS. Land application systems for nitrogen removal are commonplace, highly reliable, straightforward to implement, and environmentally sound. The active component of the system could be located anywhere, but it is assumed that it would be near the SPP to minimize conveyance costs. The passive system would operate generally as described previously, except that nitrogen loading would be reduced. The active system would beneficially use all of the nitrogen from the ITS, and the passive system nitrogen demand would be met exclusively from groundwater interception by passive system roots. All irrigation of the passive system would be with reclaimed water, carrying a minimal nitrogen load. This conformation should have the effect of maintaining the benefits of the ITS, while retiring most of the storage requirement and supplanting the need for evaporative treatment of ITS effluent.

The active component could be sized to fit the problem in terms of pounds of nitrogen per year, and would only be required to operate for a limited number of years, until source control and other component remediation technologies were fully implemented and functional. A storage system would be required to accumulate non-growing season flows collected by the ITS. The estimated volume for this storage is approximately 600,000 gallons, to store winter flow from the ITS. This assumes that the current infiltration and inflow of surface water to the ITS would be eliminated. Methods for doing this would include capping the area over ITS trenches. Water collected in the ITS would, therefore, be similar in volume to groundwater inflow described in Table 2-1 of *Solar Ponds Plume Remediation and Interceptor Trench System Water Treatment Study* (RMRS, September 1997). Water quality would be increased from the diluted 275 mg/L nitrate currently entering ITS storage to about 785 mg/L.

Based on the nitrogen load in off-season and excess in-season flow from the ITS, the estimated size of the active system required for agronomic rates of nitrogen application (approximately 150 lb/acre) is approximately 16 acres. We have assumed pretreatment to remove uranium before irrigation in the active system, which would be sited outside of the plume footprint. The active system's irrigation demand not met by ITS water would be made up with reclaimed water. The irrigation system would be subsurface drip.

The plant mix used in the active system would be either a mixture of herbaceous (mostly grasses) and trees, or strictly herbaceous. Trees would be included only if the system were to be sustained for a period sufficient to allow trees to mature and contribute.

Site Description and Project Delineation

This section describes site characteristics including the location and nature of the SPP, soils and topography, habitat, and hydrogeology. These site characteristics help define the project area for the phytoremediation system.

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Solar Ponds Plume Location and Nature

The SPP is shown in Figure 2. From the source area under the solar ponds, groundwater flow elongates the SPP in a northeasterly direction. The SPP extends from directly beneath the solar ponds north northeastward toward North Walnut Creek. The area includes the relatively level terrace upon which the ponds are constructed, the moderately sloping, north-facing hillside, and the southern riparian area of North Walnut Creek.

The SPP map was interpolated from groundwater concentration data collected in monitoring wells shown on Figure 5. The 100 and 500 mg/L iso-concentration lines for the SPP encompass 30.2 acres and 15.1 acres, respectively.

Soils and Topography of Site

Properties of soils present at the site were obtained from the Soil Survey of Golden Area, Colorado (USDA/SCS, 1980). Soil map unit delineations and topography are shown together on Figure 3. Typical properties of these mapping units are described below.

Passive System

Figure 3 shows that most of the area of downgradient from the solar ponds is steep (ranging from 10 to 25 percent slopes). The North Walnut Creek riparian areas and areas within the fence near the solar ponds are much flatter. In steeper areas, tree planting operations and irrigation should be approximately parallel to the topographic contours.

A significant portion of the SPP area is artificial fill. Reported soil properties are for the native soil and may not relate to properties of the fill. Furthermore, the scale of soil variability required grouping of soil series into complex mapping units that could only be subdivided by a more focused mapping effort. Therefore, a site-specific soils investigation (test pit excavation and description, sampling and analysis of observed profiles) will be needed during predesign of remediation projects that, like phytoremediation, depend on soil. Table 1 summarizes key soil properties with respect to design of the phytoremediation system

The alluvial area immediately adjacent to North Walnut Creek is mapped as a Haverson loam. This series is deep and well drained. The surface 0 to 6 inches has a loam texture, 6 to 40 inches is stratified clay loam and gravelly loam, and 40 to 60 inches is stratified very gravelly loamy sand. Available water holding capacity is high and the effective rooting depth is 60 inches or more. Irrigation is typically needed for plant establishment and during dry periods. Applications of nitrogen and phosphorus are needed to maintain fertility.

The predominant upland soil mapped above the SPP is a Denver-Kutch-Midway clay loam. This is a complex of three soils that could not practically be mapped individually at the scale used in this survey. Slopes range from 9 to 25 percent. The Denver component is clay and clay loam to a depth of 60 inches. The available water holding capacity is high and the effective rooting depth is 60 inches or more. Based on other site data, it is likely that the Denver component of this complex predominates in the area of the SPP. The Kutch and Midway soils in this complex are shallow, overlying soft shale that appears to significantly limit the depth available for plant roots, although some rooting into the shale could occur. The Kutch component is clay loam and clay overlying interbedded soft shale at approximately 26 inches. The available water holding capacity is low and the effective rooting.

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TABLE 1
Soil Properties SPP Area

Map Unit	Name	Drainage	Permeability Class	Hydrologic Group	Subsoil Permeability (in/hr)	Irrigation Limitations	Depth to Bedrock
31	Denver-Kutch-Midway clay loams, 9-25 percent slopes	Well drained	Slow	C to D	0.06 to 0.6	Percs slowly, slope, depth to rock	6 to >60 in
45	Flatirons very cobbly sandy loam, 0-3 percent slopes	Well drained	Slow	C	0.6 to 2.0	Large stones, droughty, percs slowly	>60
60	Haverson Loam, 0-3 percent slopes	Well drained	Moderately slow	B	0.2 to 0.6	Flooding	>60

Source: Soil Survey of Golden Area, Colorado (SCS, 1980).

depth is restricted to 20 to 40 inches. The Midway soil is even more restrictive to plant rooting, with soft shale present at a depth of 14 inches. The effective rooting depth is restricted to only 6 to 20 inches.

A small area included within the SPP is mapped as Flatirons—very cobbly sandy loam. This is the predominant soil map unit from the solar ponds area extending eastward. It is deep and well drained. Typically, the surface 0 to 13 inches is very cobbly sandy loam, from 13 to 18 inches is very gravelly clay, from 18 to 44 inches is very gravelly sandy clay, and from 44 to 60 inches is very gravelly sandy clay loam. Both permeability and available water holding capacity are low.

A set of 5 soil samples was collected as part of the site characterization for the phytoremediation system. Samples were taken from an area centered on the main part of the SPP at the downgradient end of the ITS. The data do not clearly indicate any significant chemical limitations to plant growth; however, agronomic interpretations are limited because of the analytical methods used. The methods used were appropriate for the sampling objectives, but not optimal as agronomic data. A range of soil textures was encountered from sandy loam to clay, with a slight trend toward increasing clay content with depth.

Active Component of Passive/Active System

Soil types described above generally dominate the surrounding areas near the SPP that could be used for the active system. The Flatirons soil and the Kutch and Midway components of the Denver-Kutch-Midway complex would be less desirable for the active system because of cobbles and depth to shale, respectively. Similar to the passive system, areas of the Denver-Kutch-Midway complex where the Denver component is dominant would probably be the most suitable for the active system even though the complex is found on steep areas. Other soil types are also available that would be desirable, but are generally a mile or more from the ITS.

Habitat

The existing vegetation above the SPP and within the phytoremediation area consists of approximately 18 acres of Reclaimed Mixed Grassland. The SPP extends beyond the existing dry grassland and the proposed phytoremediation area to Walnut Creek. This area of the SPP was omitted from the passive system because of its designation as suitable Preble's Meadow Jumping Mouse (*Zapus hudsonius preblei*) habitat.

The omitted area includes approximately 4.3 acres of primarily Riparian Woodland with small patches of Short Upland Shrubland and Willow Riparian Shrubland. The uppermost reaches of the Walnut Creek Riparian Woodland in the area of concern include approximately 2 acres of known habitat for the Jumping Mouse. All captures of the Jumping Mouse at Rocky flats in 1996 were within 82 feet of streams. The interface between the riparian vegetation and the drier, mixed grassland includes a buffer, approximately 75-feet wide, designated as Suitable Habitat for the Jumping Mouse (Figure 4).

The phytoremediation area avoids areas of Known and Suitable Habitat for the Jumping Mouse, which on May 8, 1998, was listed as a federally threatened species by the U.S. Fish and Wildlife Service (USFWS). Actual criteria used for the designation of Suitable Habitat

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by PTI Environmental Services are unknown but probably relate to distances from water and the juxtaposition of riparian and upland habitats.

Preble's Meadow Jumping Mouse has not been studied as extensively as other subspecies of jumping mice. It occurs mostly in low undergrowth consisting of grasses and forbs in riparian corridors with trees and shrubs. This mouse is adapted for digging and constructs underground burrows for hibernation. Dense upland grasslands adjacent to riparian corridors may be used for hibernation sites. Recent studies suggest that this subspecies has a broad range of ecological tolerances and, while it requires diverse vegetation and well developed cover, these requirements can be met in a variety of circumstances (Meaney et al., 1997). The USFWS, in listing Preble's Meadow Jumping Mouse, recognized the potential for adverse impact of bioremediation projects. However, they also indicate that water related projects that do not eliminate, degrade, or fragment existing habitat, and extend moist habitats with dense vegetation, can greatly benefit Preble's Meadow Jumping Mouse.

If necessary for phytoremediation of the SPP, it appears that the conflict between current habitat delineations and potential passive system footprint could be resolved without compromising either Jumping Mouse habitat or remediation goals. This would require focused review of habitat extent and requirements within this area, an effort to ensure that the phytoremediation system provides Jumping Mouse habitat benefits, and monitoring of the Jumping Mouse habitat within the system and a control area outside of the system.

Hydrogeology

To determine the effectiveness of a long-term transition from an active to a passive phyto-remediation system, water availability in the cottonwood root zone must be evaluated. Groundwater levels in the alluvial and artificial fill soils have been monitored for several years at the Rocky Flats solar ponds site. Monitoring well locations in the area are shown on Figure 5.

Groundwater is highest in late spring to early summer, during peak recharge from spring rainfall and snowmelt. Figure 6 shows minimum depths to groundwater. This figure was compiled from a combination of analyses of hydrogeologic interpretations by others and original interpretation of well hydrograph data. Areas identified by other analyses and our own interpretation are differentiated by color, as indicated in the legend on Figure 6. Light purple and beige shading indicate areas where the groundwater is typically within 10 feet of the surface at some point during the year. There are approximately 24 acres of land where groundwater is within 10 feet of the surface. Establishing a long-term, passive phytoremediation system is feasible in these areas.

In the area shaded in dark purple, groundwater comes within 10 to 15 feet of the surface during the year. This area encompasses approximately 2 acres. The greater depths to groundwater in these areas result in less groundwater availability to cottonwood (or to other plants') roots and thus may limit the long-term success of non-irrigated cottonwood.

Conceptual Design

Task 3 of the Solar Ponds Plume Conceptual Design and Evaluation of Phytoremediation Technology included the development of preliminary design parameters for a phyto-remediation system. These parameters are finalized in this conceptual design report.

Parameters pertinent to the conceptual design are listed here and discussed in the following sections:

1. Plant Selection and Physiological Considerations
    a. Identification of potential vegetation (plants/trees) that might be used for phytoremediation
    b. Plant/tree life expectancy
    c. Time to establish root zones
2. Evapotranspiration Rates and Irrigation Requirements
    a. General Climate
    b. Reference Evapotranspiration
    c. Cottonwood Evapotranspiration
    d. Irrigation Requirements
3. Nutrient and Contaminant immobilization and Remediation Processes
    a. Nitrogen Uptake Rates
    b. Uranium Uptake Rates
    c. Fate of Uranium in Biomass
4. Other Parameters Pertinent to Hydrogeologic Analyses

Plant Selection and Physiological Considerations

Selection of appropriate plants for the phytoremediation system and other aspects of the conceptual design are driven by a number of considerations as described in the following section.

Identification of Potential Vegetation (Plants/Trees) that Might be Used for Phytoremediation

Passive System. The objective of the remediation project would be to reduce recharge of groundwater and soluble constituents (nitrate, uranium, VOCs) to Walnut Creek. Specifically, final remediation must bring the site into continuous compliance with a water quality standard for nitrate of 10 mg/L in groundwater adjacent to Walnut Creek by the end of active site cleanup (year 2006). During interim operation (between the years 1999 and 2006), the interim water quality standard for nitrate will be 100 mg/L, if interim operations will assure compliance with the 10 mg/L nitrate standard after the year 2006. Uranium water quality standards must also be met. The current standard is 10 pCi/L, based on ambient conditions, but this is subject to change if a health-based standard is adopted (most recently proposed at 30 pCi/L).

Correspondence in Appendix B indicates that a phytoremediation system should be passive. That is, irrigation for the purpose of crop establishment would likely be acceptable, but thereafter, the irrigation system would be retired. Furthermore, the vegetation should

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be consistent with existing habitat types; that is, native plants and plant communities should be emphasized.

Once the SPP source area is capped, groundwater levels might be expected to decline. The system should evolve in a relatively natural way in response to this anticipated change in hydrology, without causing any severe ecological or aesthetic disruption.

Given these constraints, vegetation in a phytoremediation system must have the following characteristics:

- Species native to the area and, if possible, the watershed.
- Deep rooting since groundwater will ultimately be taken up directly by the plant, and not intercepted by the ITS. Further, the depth to which plants can take up significant amounts of water will partly determine effectiveness in SPP interception.
- The plant community should take up as much water and nitrogen as possible. Nitrogen recycling in senescent biomass should be minimized, to the extent possible.
- Phreatophytes, or plants that thrive under saturated conditions, will be preferred. The system will really be doing its job when groundwater levels are high, so that it must be using as much water as possible from the wettest soil.
- Rapid plant growth will allow for rapid development of the system, prompt performance assessment, and early realization of lower constituent loading to Walnut Creek.
- A phytoremediation "track record" for the plant community would be helpful since it would facilitate projection of benefits and increase the probability of success.
- When site hydrology changes, the plants should either persist, or die and make way for succession by other native plants.

Woody perennials (shrubs and trees) are generally more deep rooted than herbaceous plants. The dominant native woody perennial in the upper watershed is cottonwood, a phreatophytic tree growing along the margin of the creek, and a user of large volumes of water during the growing season. Cottonwood grows quite rapidly relative to most trees. Poplar, in the same genus, has been widely planted in phytoremediation systems, a number of which have focused on control of hydrology and/or nitrogen. When a site dries, mature cottonwood will likely extend their roots to obtain water. Under sufficiently dry conditions, they will eventually thin, die off, and fall over. With the removal of this tree canopy, native understory should establish readily, since cottonwood leaf litter is not phytotoxic.

It is, therefore, expected that native cottonwood will make up the bulk of the phytoremediation system, being interplanted with existing, herbaceous vegetation. Once established, the expanded cottonwood stand will likely shade out many of the herbaceous species, resulting in an increasingly pure stand of cottonwood.

However, the optimal plant community for phytoremediation may need to be modified somewhat to achieve site habitat goals and requirements. If this is the case, one likely change will be a reduction in tree density, or planting of less area. A reduction in density would delay achievement of peak evapotranspiration (ET) rates by delaying closure of the

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cottonwood canopy. Areas planted with other species would likely have lower ET and extract less groundwater per unit area.

Passive/Active System. The appropriate plant mixture for the active component of the passive/active system depends upon the term of operation. If short term, a strictly herbaceous system would be used because the additional cost of establishing trees would not be justified. After cessation of irrigation, trees established in the active system would not survive because they would not have access to alluvial groundwater in most likely locations to be used in the active system. Nitrogen utilization for an irrigated grass system would be similar to a combined grass and tree system, but without grass biomass removal, long-term nitrogen removal from the site would be substantially lower.

A number of herbaceous species could be utilized in the active component of the system. Planting a diverse mixture of species would increase the habitat values of the area and allow plants to take advantage of microsites best adapted to individual characteristics. Grass plants would predominate the seeding but other plants, including adapted forbs or legumes, could be included. All of the wheatgrasses (Slender, Tall, Crested, Intermediate, and Western) have been found on site and could be included in a seed mixture for the active system. Other grass species could include Blue Grama, Smooth Bromegrass, Reed Canarygrass, Orchardgrass, Big Bluestem, Little Bluestem, and Buffalograss. Inclusion of a variety of species also serves to decrease risk.

Plant/tree Life Expectancy

Passive System. Native cottonwoods live for many decades, given suitable growing conditions. With attrition, natural reproduction may not maintain the stand throughout the area currently occupied by cottonwood. Groundwater recharge upgradient should decline with capping of significant land areas, so unless runoff is routed to Walnut Creek, this area will be drier in the future.

In short rotation and favorable environments, hybrid poplar trees are harvested in a 7-year rotation. This is probably equivalent to the growth that might occur in 10 years at Rocky Flats, given the shorter growing season and differences between native and hybrid varieties. At this point, thinning would allow the continued growth of other trees. Given the need for comprehensive rooting, a more gradual thinning process might be advisable to maintain performance and to maximize stand life span.

While cottonwoods do reproduce via seeds, their main form of propagation is by coppicing (or sprouting from existing plant material.) New sprouts often emerge from existing roots some distance from the original stem. In effect, this propagates cottonwood throughout a local area favorable to its own survival so that, without active plantation management, the plantation will grow into its most favorable habitat. This propagation will most likely follow available water and nitrogen (i.e., the SPP) as their availability limit growth on much of the site.

Passive/Active System. There should be little difference in life expectancy for the passive and active systems. All plants used are perennial and will survive for many years. If irrigation is no longer provided in either system, the plant community will naturally transition to appropriate species.

Time to Establish Root Systems

Passive System. Observations of rooting in hybrid poplar plantations, a close relative of native cottonwood, indicate extension to about 6 feet within about 3 years, and to 12 feet in 6 years, given favorable soil conditions. Many of these plantations are located in areas with longer growing seasons than are enjoyed at Rocky Flats. Therefore, 4 years may be required for this type of root extension at this site. Mature, native cottonwood root more extensively and over long lateral distances (over 100 feet, personal observation, Salem OR, 1997), if tree densities are sufficiently low.

Soil depth, density, and other physical conditions will also affect rooting. Very dense soil layers and bedrock will impede rooting. Roots will penetrate fractures if moisture conditions allow.

Irrigation management will also affect rooting patterns. Roots will have better extension in wetter soil volumes, when the trees' water requirements are not met within the current extent of rooting. In practical terms, deeper rooting is encouraged by infrequent, rather large irrigation events. These tend to fill the soil profile, and then allow it to dry between events, encouraging plants to pursue moisture by rooting downward.

Projections of rooting at the site will be increasingly certain with additional site-specific information on soil conditions and groundwater levels.

Passive/Active System. Rapidly achieving maximum rooting depth in the active system is less critical than in the passive system. Irrigation would be managed to optimize nitrogen uptake rather than rooting depth, possibly resulting in shallower rooting even for trees that might make up part of the active system. Root systems for herbaceous species for both the passive and active systems would be largely confined to the surface 1 to 2 feet, most of which would occur during the first year.

Evapotranspiration Rates and Irrigation Requirements

ET rates are a critical factor in the design of most phytoremediation systems. Reasonably accurate estimates can be made based on knowledge of local climate and growth characteristics of selected plants.

General Climate

The growing climate of Rocky Flats is typical of the Front Range of the Rocky Mountains. Winters are cold with average minimum temperatures at Longmont, CO (Elevation 4950) dipping to 11.5 degrees Fahrenheit (°F) during the month of January. (Western Regional Climate Center). Summers are very warm with an average maximum July temperature of 88.5°F. Because the Rocky Flats Facility is approximately 1,000 feet higher (5,900 feet), average temperatures will tend to be slightly cooler than those at Longmont. Assuming an unsaturated adiabatic temperature gradient with height (≈ 5°F/1,000 feet), it is expected that the average maximum and minimum temperatures may be decreased by up to 5°F. Cold temperatures generally restrict the active growing season to mid-May through early September.

Precipitation type and amount also varies with season. The average annual precipitation observed at Longmont is 13.77 inches. Annual precipitation at Rocky Flats has been

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reported to be closer to 15 inches. Over one-half of the precipitation, 7.81 inches, falls during the summer months May through September, in the form of high intensity convective storms. Snowfall is significant throughout this region, averaging 35.5 inches annually. It may fall as early as September or as late as April. The Front Range is generally a semi-arid region with occasional moist airmass intrusions emerging from the Great Plains. Correspondingly, there are typically over 300 days of sunshine per year.

Reference Evapotranspiration

Climatic conditions determine the long-term expected evaporative demand or crop water use (also referred to as evapotranspiration). Average annual ET of an alfalfa reference crop at Longmont is equal to 30.9 inches (Central Colorado Water Conservancy District, 1997). This estimate can be adjusted to yield ET estimates for the proposed cottonwood phytoremediation crop by use of crop coefficients. Monthly cottonwood ET estimates are provided in Table 2. The evaporative demand during the summer months is relatively high, but the annual demand is kept in check by the relatively short growing season. Values are given for 1- through 7-year-old trees. It is assumed that crop coefficients (and ET) will not change significantly after 7 years of growth, when cottonwood canopy closure will be complete. Cottonwood ET can be expected to increase from approximately 15.3 inches per year for 1-year-old trees to 28.4 inches per year for 7-year olds.

Adjustments to the reference ET for the 1,000-foot elevation difference between Rocky Flats and Longmont, Colorado, were considered. Considerable debate exists in the scientific literature as to the effects of altitude on evapotranspiration rates. This is because plant transpiration does not have a simple linear relationship to altitude, but rater involves numerous other biophysical parameters. Some research suggests that plants can respond to altitudinal changes in a variety of ways. These differences may in fact be due to changes in the micro-climate of the plant, arising from extreme topographic variations associated with mountainous terrain, and as opposed to larger scale climatic differences such as differences in radiation, CO_2, and water-vapor concentrations, diffusion coefficients, and temperature. Lacking a formal, accepted adjustment procedure or substantial microclimate data obtained at the Rocky Flats site, no adjustment was made to the alfalfa reference ET from Longmont. Neglecting altitudinal adjustments should result in conservative estimates of annual crop water use, and hence of plant water requirements. This is because the unadjusted estimates will slightly over-predict the water required for the site due a presumed shorter growing season at the Rocky Flats site.

Cottonwood Evapotranspiration

For production, poplars are planted at a wide range of spacings depending on objectives, ranging from 300 to 1,200 trees per acre. In native stands, higher densities can be maintained where water is plentiful, and would thin to much lower densities in drier areas. One of the advantages of planting at high densities is that the stand closes its canopy and, therefore, commences significant remediation sooner than lower planting densities. We recommend initial densities at this site should be approximately 870 trees per acre where habitat requirements allow. Some thinning will be desirable in later years as trees grow, especially along the margins where water will be scarce after retiring the irrigation system.

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TABLE 2
Estimated Cottonwood Stand ET by Age for Rocky Flats, Colorado

Month	Alfalfa ET at Longmont (inches)	Cottonwood ET (inches) Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0.16	0	0	0	0	0	0	0
April	2.05	0.86	0.90	0.82	0.82	0.88	0.92	0.96
May	4.03	1.73	2.10	2.10	2.22	2.34	2.42	2.50
June	6.14	2.89	3.68	4.30	4.61	4.79	4.91	5.03
July	7.52	3.84	5.19	6.39	6.77	6.99	7.14	7.29
August	6.4	3.52	4.86	8.00	8.00	8.19	8.32	8.45
September	3.85	2.12	2.93	3.12	3.35	3.47	3.54	3.62
October	0.76	0.38	0.54	0.49	0.53	0.55	0.57	0.59
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Total	30.9	15.3	20.2	25.2	26.3	27.2	27.8	28.4
Seasonal Crop Coefficient (percent)		65 percent	82 percent	85 percent	88 percent	90 percent	92 percent	

Crop coefficients used were adjusted from estimates provided by Gochis and Cuenca (1998) and Cuenca and Kelly (1998). Both estimates determined hybrid poplar water use and crop coefficients from soil moisture measurements in an irrigated agronomic setting. Estimates of crop coefficients for 1- and 2-year-old trees were adjusted from the values presented in Gochis and Cuenca due to differences in plant spacing. The spacing proposed for the Rocky Flats phytoremediation system is expected to be 5 feet by 10 feet, (870 trees per acre), as opposed to 8 feet by 10 feet, or 600 trees per acre, as given by Gochis and Cuenca. The difference in spacing is important primarily during the first few years of growth in that a tighter spacing speeds canopy closure, yielding a larger surface for evaporation. Correspondingly, crop coefficients for 1- and 2-year -old trees were increased by approximately 12 percent from the values reported by Gochis and Cuenca (1998).

Estimates of crop coefficients for 3- and 4-year-old trees were taken directly from Cuenca and Kelly (1998). These estimates were not adjusted, as the tree spacing from their work is similar to that proposed at Rock Flats. The crop coefficients for 5-, 6- and 7-year-olds were increased by 3 percent, 2 percent and 2 percent, respectively, from year to year to simulate minor increases in canopy density resulting in slightly higher leaf area indices.

Irrigation Requirements

The monthly irrigation requirement can be estimated as the amount of projected ET that is not satisfied by precipitation. Monthly precipitation at Rocky Flats was estimated by using mean monthly precipitation values observed in Longmont and the ratio of annual precipitation observed at Longmont to that observed at Rocky Flats. It was also assumed that the rainfall is 100 percent effective in depressing ET. When rainfall is less than 100 percent

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efficient, (i.e., some runs off or infiltrates but is not taken up by plants), the irrigation demand will be somewhat greater. The generally conservative sizing of the irrigation facilities, and tolerance of cottonwood to deficit irrigation, offset any deficit due to non-effective rainfall.

The results of these calculations are shown in Table 3, with annual irrigation depths ranging from 7 to 19 inches, increasing as the trees mature.

TABLE 3
Average Monthly Precipitation and Irrigation Requirements

	Rocky Flats Precipitation	Irrigation Requirement (inches)						
Month	(inches)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
January	0.4	0	0	0	0	0	0	0
February	0.4	0	0	0	0	0	0	0
March	1.2	0	0	0	0	0	0	0
April	1.8	0	0	0	0	0	0	0
May	2.7	0	0	0	0	0	0	0
June	2.0	0.93	1.73	2.35	2.65	2.84	2.96	3.08
July	1.2	2.64	4.00	5.20	5.57	5.80	5.95	6.10
August	1.3	2.18	3.52	6.66	6.66	6.85	6.98	7.10
September	1.3	0.81	1.61	1.81	2.04	2.15	2.23	2.31
October	1.5	0	0	0	0	0	0	0
November	0.7	0	0	0	0	0	0	0
December	0.4	0	0	0	0	0	0	0
Total	15.0	6.6	10.9	16.0	16.9	17.6	18.1	18.6

Note: Rocky Flats precipation by month was estimated using monthly averages at Longmont and total annual precipitation for both sites.

Given the objectives of the passive system, actual operation will likely include less irrigation than specified in Table 3, especially after year 2. The primary purpose of irrigation will be to establish vegetation, train rooting into deeper layers for maximum access to groundwater, and then to allow groundwater to satisfy the maximum proportion of the plants' water needs possible. As the trees mature, this will occur.

On the other hand, the active system will be irrigated throughout its years of operation. The objective in the active system is not groundwater uptake

Also, a native that is locally adapted will exhibit much greater stomatal control (resulting in lower ET) than a generic hybrid poplar will. Hybrid poplars were studied to develop crop coefficients used to develop ET estimates (Table 2) and irrigation requirements (Table 3). Since hybrid poplar tend to use more water than native cottonwood, this approximation likely overestimates Cottonwood ET and irrigation requirement.

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In summary, the following considerations must be taken into account in the long-term site plan:

- Areas that contain mature stands currently transpire up to 8.5 inches per month, where sufficient water is available. Peak irrigation demand for mature trees is over 7 inches per month, and peak demand in year 2 is already 4 inches.
- When groundwater is within or near to the root zone, a significant proportion of the projected ET should be satisfied by groundwater.
- When irrigation is removed from new plantings, their ET will decline during periods of moisture scarcity (when groundwater and precipitation are not sufficient to satisfy demand).
- Nitrate will move to the plant in groundwater, but will only be consumed by trees in quantities that they can assimilate (see the next section).
- During wet years, irrigation demand will be less and ITS flow will be more. Since the active system has more than enough hydraulic capacity relative potential ITS flow, increased volume of ITS water do not pose a problem.

Even though the average irrigation requirement for the winter months is near zero, irrigation may be required virtually any time of year at this site, if a period of fair weather occurs. Even when trees have no leaves, they can lose enough water in this dry climate to cause stress. Therefore, the irrigation system needs to be operable throughout the year, and site monitoring during establishment needs to detect and respond to periods of water stress.

Nutrient and Contaminant Immobilization and Remediation Processes

Nitrate-nitrogen and uranium isotopes are the key contaminants in the SPP. The proposed phytoremediation system must adequately address both. Critical system parameters therefore include the following:

Nitrate uptake rate. This provide a notion of how much nitrogen the passive, and passive/active systems will be able to immobilize. With estimates of nitrate load in the ITS, it also determines the size of the active component of the passive/active system.

Carbon production. Nitrogen uptake by plants is one mechanism of phytoremediation. Another is enhancement of soil microbial activity (including denitrification) through a variety of means, especially the production of assimilated carbon for the microbes to "eat" as they transform nitrate.

Uranium uptake rates. The presence of uranium in the SPP makes this a concern for existing vegetation and for new plantings. If uranium removal technology is implemented, the cause for this concern should be greatly reduced.

Nitrate Uptake Rates

The anticipated treatment mechanism for this system is two-fold:

- Hydrologic control: the volume of groundwater recharging the creek will be reduced

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- Nutrient removal: uptake and denitrification within the extensive, and biologically active root zone will reduce SPP nitrate load

Much of the nitrogen taken up by cottonwood is restored to the land in leaf litter, but some is stored in root and stem biomass until the wood itself falls and decays. About 105 to 200 lb/acre/year are used by production stands of poplar. Native cottonwood should be within the 85 to 160 lb/acre/year range, depending on their vigor. Total load in the current ITS is approximately This results in the following phytoremediation impacts for nitrogen, from uptake alone:

- In the 15-acre passive system, **2,250** lb of nitrogen per year, or about **33 percent of the current ITS load.**

- In the 46-acre active component of the passive/active system (if it is planted with cottonwood), **6,900** lb of nitrogen per year, or **100 percent of the current ITS load.**

Other nitrogen losses (natural attenuation by processes other than uptake) can be considerable. Carbon and microbial activity often limit the rate of denitrification in groundwater. Under native grass cover, most organic matter cycling takes place in the upper foot of soil. When the root zone (and associated carbon cycling and microbial populations) extend to 6 feet or more, and nitrate-rich groundwater periodically enters this zone, denitrification rates at the site should be considerably boosted. It is difficult to provide a numeric estimate of this removal, but natural attenuation can rapidly reduce groundwater concentrations when conditions are favorable. Field monitoring can be designed to estimate nitrogen loss and immobilization, including sampling of plant tissue, soil, and groundwater, as well as direct measurement of attenuation processes (like denitrification), as needed.

Carbon Production

The most basic function of green plants is photosynthesis, a process that involves the fixation of atmospheric carbon, changing it from its most oxidized form (CO_2) to highly reduced forms (organic chemical compounds such as sugars). This fixed carbon is returned to the soil in a number of forms, including leaf litter, root growth and root turnover in the soil, and release of organic compounds from roots (root exudates). Furthermore, these carbon inputs to the soil can be utilized by soil microorganisms to increase rates of denitrification. Over time, there is the potential for plant carbon inputs to reduce the need to replace carbon amendments in the proposed funnel and gate system.

Root data, particularly under field conditions, is difficult to obtain. Estimates for root biomass can be made through knowledge of typical root-to-shoot ratios (RS ratio). A logarithmic linear relationship between shoot weight and root is usually found. Table 4 shows estimates used in the establishment of CH2M HILL's Riverbend Landfill project.

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TABLE 4
Estimates for Hybrid Poplar Growth Used at Riverbend Landfill

Year	Root Biomass (lb of dry matter/acre)	Stem Biomass (lb of dry matter/acre)	Root : Shoot
1	200	1500	0.13
2	2500	8000	0.31
3	4700	14,400	0.33

Typical RS ratios for trees are 0.15 to 0.20 (Bray, 1963 as cited in Kramer and Boyer, 1995), however these data vary widely by species, age, and environmental conditions. Heilman et al. (1994) found RS values for 4 year-old hybrid poplar trees in Washington were 0.34 to 0.42, roughly similar to the Riverbend design data. Native cottonwood are assumed to have a similar RS ratio.

The release of root exudates also varies a great deal depending on plant species, age, environmental conditions, and possibly other factors. Separation of the normal turnover of plant roots (death and cell lysis) from releases of carbon from living tissue (exudation) is also difficult. Both processes result in the release of organic carbon to the soil, are extremely difficult to measure under field conditions, and yet are considered extremely important in phytoremediation systems. Whipps and Lynch (1985) found 10 to 20 percent of total photosynthate production was released into the soil. Vancura (1964) found 7 to 10 percent release. Some studies have suggested that under some conditions, up to 50 percent of total photosynthate production may be released to the soil (A. Blackmer, 1989, personal communication). A reasonable assumption then is that the proposed cottonwood system would be expected to release at least 15 percent of total plant biomass as carbon-containing compounds into the soil in the form of exudates and turnover of fine roots.

Heilman et al. (1994) provided detailed information on hybrid poplar biomass production. For four-year old trees, they found a mean annual above ground biomass production of 5 to 10.9 tons/ac/yr (several clones). The root biomass ranged from 8.6 to 16.9 tons per acre, or 2.1 to 4.2 tons/ac/year. Roots extended to greater than 10.5 feet in 4 years, although most roots occurred in the upper soil. Irrigated hybrid poplar trees growing in sandy soils in eastern Oregon were found to have extensive rooting to at least 12 feet below the surface after 6 years of growth.

A survey conducted in the Willamette Valley, Oregon found that above-ground biomass in hybrid poplar planted at 600 trees per acre with medium productivity would produce approximately 15 tons per acre of above ground biomass by the 5th year (Withrow-Robinson, 1994). Table 5 shows estimated total carbon input from the phytoremediation system based on literature values adjusted for altitude and differences in yield potential between native cottonwood and hybrids. The production of leaves is neglected for this analysis. It is assumed that annual leaf fall will primarily serve to increase soil organic matter levels near the surface and/or be lost as CO_2, and will not significantly contribute to groundwater carbon.

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TABLE 5
Estimated Input of Carbon to Soil-Groundwater System by the Phytoremediation System

Year	Total Biomass, Roots and Stem (lb/ac)	Carbon Input (lb/ac/yr)
1	1500	112
2	6000	450
3	11,400	855
4	20,000	1500
5	25,000	1875

Assumptions: Root turnover and root exudate production is assumed to be 15 percent of total plant biomass. Carbon content is 50 percent of root turnover and root exudate dry matter.

This results in the following carbon contribution from roots of the phytoremediation system components:

- In the 15-acre passive system, **14 tons** of carbon per year in the mature system, 3.4 tons per year by year by the second year.
- In the 46-acre active component of the passive/active system (if it is planted with cottonwood), **43 tons** of carbon per year in the mature system. Although this contribution would be outside of the plume area, it would still fuel denitrification processes that would consume nitrogen collected in the ITS and applied to the active system.

Although an unknown fraction of this carbon contribution will be lost as CO_2 in aerobic zones or accumulate as increased organic matter, the data in Table 5 indicate that the proposed system will contribute a significant quantity of carbon to the soil-groundwater system. Since the lack of available carbon is most likely limiting denitrification, the phytoremediation system should increase overall rates of nitrogen loss through denitrification.

If the active component of the passive/active system is herbaceous, carbon inputs and denitrification deep in the soil will be significantly less than in the passive system with deep rooted trees. The irrigation system in the active system would also be managed in a way that would not promote denitrification. In a herbaceous system (mostly grasses), most rooting will occur in the surface 1 to 2 feet, and carbon will mostly accumulate as increased organic matter. Carbon contributions to groundwater in the passive component of a passive/active system would be similar to the strictly passive system.

Uranium Uptake Rates

Because uranium is present at elevated levels in the SPP, potential plant uptake of uranium is a consideration in the implementation of both the passive and passive/active phytoremediation systems.

Passive System. Preliminary data collected at the site suggest somewhat higher uranium values in the leaves of deep-rooted trees at North Walnut Creek as compared to a control site, suggesting a relationship with the presence of the SPP. Rates of uptake are expected to

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remain low because under the alkaline pH conditions expected the vast majority of uranium is expected to adsorb to the roots and not be translocated to the above-ground parts of the plant.

In the course of a literature review ("Rocky Flats Literature Review – Plant Uptake of Uranium", March 29, 1998 from Jim Jordahl and John Dickey to Kelley Hranac et al.), no studies were found that described trends in life-cycle uranium uptake in cottonwood or other plants. Laboratory studies generally concerned juvenile plant material. Root-membrane barriers to plant uptake of heavy metals are generally least developed in young plants, making their rates of radionuclide uptake per unit volume water uptake, or per unit plant biomass, higher than those found in mature plants. Field studies generally report native plant concentrations at a point in time, and typically describe total soil uranium concentrations rather than bioavailable concentrations.

Field conditions could potentially increase concentrations in older plants. For example, mature trees will be more deeply rooted and have greater access to groundwater, a possible source of uranium. For established perennial plants such as poplar, it may be possible to relate uptake of uranium each growing season to changing water uptake rates. No literature was found to support such a calculation.

Passive/Active System. Uranium would not be an issue in the active component of the passive/active system because any groundwater removed from the SPP would be pretreated to remove uranium before application outside the plume. The passive component would only be irrigated with reclaimed water from the wastewater treatment plant as needed for establishment. The only potential uranium uptake by the passive component of the passive/active system would be from groundwater uptake, which is expected to be limited.

The Fate of Uranium in the Biomass

Data collected from plants at the site showed the highest concentration of uranium in cottonwood leaves, with lesser amounts in the branches. The review of the literature found that the fate of uranium in plant tissue varies considerably, and that uptake of uranium is highly plant- and soil-specific. Soil factors influencing uptake include the amount and species of other cations present, the type of clay minerals, and pH. Several recent papers have reported results with rhizofiltration (adsorption of uranium to plant roots). Hydroponically-grown sunflowers successfully removed uranium from a groundwater passed through the system. Almost all (99 percent) of the uranium removed from the water was concentrated in the roots. **Shoot uranium concentrations were not significantly different from control plants** (sunflower not grown with U-enriched solution). In addition, a study of oat seedling growth in soil showed that most uranium accumulated in the roots, and **was not translocated** to the shoot or seed. No reports found specifically describe uranium uptake by *Populus spp*.

Other Parameters Pertinent To The Hydrogeologic Analyses

CH2M HILL (Dickey and Jordahl, 1998) reviewed project status with staff at McLane Environmental in a conference call on April 17, 1998. CH2M HILL and McLane exchanged copies of their respective scopes of work and some of their draft work products. McLane described their modeling effort and model capabilities, and the need for CH2M HILL to

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assist with boundary conditions as the conceptual design is developed. It was agreed that the analysis should include design of the system considering two scenarios: one assuming no alteration of Prebles mouse habitat and a second assuming optimization of the system ignoring Prebles habitat boundaries. This report focused on the no impact scenario. However, it is noted that the area excluded from the passive system to avoid Prebles habitat was 4.3 acres. Its inclusion would add 29 percent to the proposed passive system area.

Current habitat delineations are based on the dependence of Prebles on riparian areas, where the phytoremediation system could conceivably provide substantial surface water quality benefits. We anticipate McLane using the groundwater model to assess the difference in performance between the two configurations. If the difference is substantial, then we recommend reviewing the possibility of refining the habitat delineation within the potential extent of the phytoremediation system. This could have the result of increasing or decreasing the riparian area that could be planted with trees for the phytoremediation system.

Summary of Design Assumptions and Criteria

Passive System

- It is assumed that SPP water can be used to establish the system, and that water from the wastewater treatment plant is available as needed to supplement or to replace SPP water as needed.
- The irrigated area will be approximately 15 acres based on the size of the SPP and avoidance of Prebles habitat. Approximately 18 acres will be planted, providing a small buffer at the plume's edges. The buffer will not be irrigated with plume water.
- Water collected by the ITS will be stored in a small modular tank and used to irrigate the passive site as needed.
- A pilot test may be conducted to determine if there is a plant uptake problem with uranium associated with the planned subsurface irrigation system.
- Water storage and the irrigation pump will be sized to irrigate ITS water every day for 2 hours
- Nitrogen uptake is expected to be at least 150 lb per acre by the third growing season and sustained thereafter.

Passive/Active System

- A barrier wall or other technology will be used to pretreat groundwater to remove uranium before application outside the SPP footprint.
- The active system consists of 46 acres irrigated to treat nitrate-laden water collected by ITS.
- ITS water will be stored in a new modular storage tank designed to accumulate non-growing season flows. Storage facilities and the irrigation pump are sized to irrigate ITS or WWTP water every day for 2 hours.

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- The active component will be irrigated with ITS water to satisfy nitrogen uptake capacity, with supplemental water supplied from the WWTP as needed. WWTP flows will constitute all of water used to irrigate the passive site, and will provide most of the water on the active site.

Assumptions common to both Passive and Passive/Active Systems

- The ITS flow is 1.05 MG per year

- The ITS trenches will be capped with vegetated, heavy-textured soil to prevent infiltration

- Surface runoff (from buildings etc.) will be minimized. Runoff from the site, especially the ITS trenches, will be maximized. This flow of clean water will then bypass the plume and dilute flow in the creek.

Hydrologic, Hydrogeologic Criteria

The major objectives of SPP remediation have to do with maintaining water quality in North Walnut Creek. Phytoremediation system criteria related to this goal include the following:

- Significantly reduced recharge of North Walnut Creek from the SPP over time will benefit North Walnut Creek water quality, since other inflow is of higher quality than SPP inflow.

- Regulatory standards must be met. Stream standards are currently 100 mg/L nitrate, changing to 10 mg/L in the year 2006, and 10 pCi/L uranium, perhaps increasing to 30 pCi/L. The point of compliance is currently in groundwater adjacent to North Walnut Creek, but this could change to an in-stream point of compliance.

- The MST's will not be available as part of the ITS in the future, but alternative storage could be provided, at no cost to the phytoremediation system, and continued operation of the ITS is an option. It would be of benefit for the phytoremediation system to accommodate flow and load from the ITS, and to require as little storage as possible to do so. Given the critical setting of the project, redundant remediation design is justified.

- Adaptive management of the site will be possible and desirable, as various component remediation and source control efforts take effect, and as climate and other site conditions vary and evolve.

System Description

General design characteristics and operation of both the passive and passive active systems are described in the following sections. Planting methods for both systems are also included.

Passive System

Two alternative phytoremediation systems have been considered. The first system, shown in Figure 7, is a passive system and was designed to alleviate the need for a large storage facility required to store year-round discharged ITS water. The passive phytoremediation system will consist of approximately 18 acres of native cottonwood trees. Approximately 15 of the 18 acres shown on Figure 7 is within the SPP and will be irrigated with its water. The buffer could be left unirrigated (as assumed in our costs), or its irrigation system could be isolated, and reclaimed water from the wastewater treatment plant would be applied. The passive system would be irrigated for a maximum of three years in order to establish a viable root system ensuring the survivability of the tree.

Daily discharge water from the ITS will be pumped from the ITS system to a 10,000 gallon regulating modular storage tank. This water will be applied daily during the growing season to the passive phytoremediation system until tree roots are established. Discharge from the ITS system will account for approximately 1.25 inches of the irrigation requirement. Supplemental irrigation water, to meet plant-water requirements for one-, two- and three-year old trees, will be supplied from the wastewater treatment plant. Depending on the age of the tree, 5 to 15 inches (2.2-6 MG) annually will be used to supplement irrigation.

The proposed passive system consists of the installation of two small scale (1 and 3 horsepower) pumping stations, one at the wastewater treatment plant and another at the modular storage tank adjacent to the sump facility of the ITS (or at the replacement for this tank). The pumping station at the ITS site is sized to deliver the daily flow from the ITS to the irrigation system. Given the high degree of topographical variation, a small booster pump may also be required to provide adequate irrigation system operating pressure. The modular storage container will be placed inside a larger containment vessel as a precaution against leakage. The unit is sized to store an average three-day flow from the ITS. This provides some storage for days when maintenance and repairs must be performed to the irrigation system. ITS discharge is not expected to be stored on days outside of the May-September growing season.

Two conveyance lines will be installed from the pumping stations to a manifold located adjacent to the 15-acre irrigation site. The two conveyance lines will be joined and connected to the field manifold, which will distribute the flows between three, 5-acre blocks. Adequate precautions will be taken to prevent any backflow of ITS water into the WWTP conveyance line. The combined flows will be applied to the phytoremediation site until a majority of the trees have rooted sufficiently to access existing groundwater. After this point the irrigation system will be disconnected and the ITS will be capped.

The irrigation system will consist of subsurface drip laterals, placed along contours, containing root-guarded emitters (see attached sample) spaced in a 5-foot by 5-foot pattern. This tight spacing will result in high application uniformity allowing the success of both planted cottonwoods and other herbaceous vegetation. Trees will be planted on a 10-foot by 5-foot spacing or, effectively, 870 tees per acre.

The monitoring system for the passive system has not been developed in detail, and is not included in system costs. However, the following components would likely be included:

- Plant tissue monitoring (leaves, stems, and initially roots, for uranium, nitrate, and total nitrogen)
- Plant biomass accumulation monitoring
- Soil monitoring (for moisture, nitrate, ammonium, salinity, organic carbon, and uranium; perhaps some in-situ measurement of denitrification)

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- Pore water monitoring in the vadose zone (for nitrate, ammonium, salinity, organic carbon, and uranium)
- Groundwater level monitoring (where the existing monitoring well network and sampling frequency may not provide adequate data density). Given the existing monitoring well density, no additional monitoring wells are expected.

Passive/Active System

The second alternative is a combined passive/active system. This alternative was developed because it can reduce the excess nitrogen load of the SPP. The active phytoremediation system will be 46 acres (over and above the 15 acres from the passive remediation system). The active system was sized based on the concentration of nitrogen in the ITS discharge stream and an estimated uptake of 150 lb of nitrogen per acre per year.

The active system's size was determined based on average nitrate concentrations in MST water, and average groundwater inflow reported for the ITS. Refinements to estimate peak-year nitrate loads, should be used to refine the size of the active system.

For the active system, ITS water will be collected year round. The annual yield from the ITS trench is approximately 1.05 MG. Storage will need to be provided for approximately 0.5 MG of ITS water collected during the wintertime (i.e., October through April). During the growing/irrigation season, water will be pumped from the storage facility to the active remediation site with a 2-horsepower pump. The irrigation system will be operated in such a manner that the available nitrogen will be irrigated when the trees can best take it up, and the storage container will be essentially empty by the end of the growing/irrigation season.

As for the passive system, discharge from the ITS system will account for approximately 1.18 inches of the irrigation requirement at the active site. Supplemental irrigation water required by the active phytoremediation site, ranging from 2.4 to 6.4 MG annually, will be pumped by a 3-horsepower pump at the WWTP. Satisfaction of this requirement will maximize the nitrogen uptake capacity of the active system. The passive phytoremediation site will be supplied with, and only with, WWTP water from this pump. The passive site will require between 2.7 and 6.5 MG of water, annually. This requirement should be met to ensure the long-term survivability of the passive remediation system.

The water will be distributed to both irrigation systems through manifolds at both sites. The active system site will be divided into three, 5.3-acre irrigation blocks. Adequate precautions will be taken to prevent any backflow of ITS water into the WWTP conveyance line. The passive system site will be divided into three, 5-acre blocks. The irrigation system will consist of subsurface drip laterals, placed along contours, containing root-guarded emitters spaced in a 5-foot by 5-foot pattern.

Passive System Planting Plan. *Grass Understory*—Grass will be planted in all of the tree areas to provide soil erosion control, maximize consumptive water use in the early years of the plantation, and to encourage deep rooting of the trees. Grasses will be used to keep the upper layer of the soil dry. Tree roots will be forced to extend deeply into the soil in search of moisture, resulting in earlier interception and utilization of the high-nitrate groundwater. An adapted, drought-tolerant but shallow rooted species such as Western Wheatgrass will be used for the bulk of the seed mixture. Other, cool-season species may be included, such as the other wheatgrasses (Slender, Tall, Crested, or Intermediate), Smooth Bromegrass, and

Orchardgrass. Native, warm-season prairie grasses may be established separately in other areas. These species would include Big Bluestem, Little Bluestem, Blue Grama, and Buffalograss. Inclusion of a variety of species serves to decrease risk and generally increases habitat values.

Trees—Native RioGrande Cottonwood will be used. It is a well adapted native tree that can root into groundwater to extract water and nitrate.

Planting Method—Achieving the earliest possible root interception of the SPP is essential. The best way to obtain this is to plant the trees as deeply as possible. Cottonwood can be established from "poles" cut to very long lengths, but rooted stock will fare better in this area with its low humidity. In many areas of the SPP, alluvial groundwater high in nitrate is present within 10 -feet of the surface. For example, 12-foot stock could be installed to a depth of 10 feet. This system would be ideal for the alluvial groundwater depths found in some areas of the SPP. However, availability of very long planting material is quite limited and requires planning 1 to 2 years ahead. Augers can be used to bore individual holes for each tree. Trees should be planted as deeply as possible, with the bottom of the root ball at average depth of summer water table if possible. Trees should be located to minimize tree rooting into the drain tiles of the ITS.

Special, deep rooting techniques have been developed for hybrid poplar trees and cottonwood. These have not been rigorously evaluated to date. Generally, these involve boring oversize holes and backfilling with materials to minimize the available water in the upper root zone. It is recommended that these methods be tried on at least a small scale at this site.

Operational Plan

Annual operation plans and costs have not been developed in detail. Some things that will need to be considered include the following:

- Winter operations need to be specified, although subsurface drip is frost-resistant.
- Irrigation scheduling should be set up based on soil moisture profiles.
- Irrigations should be long, deep, and infrequent, only when the site requires the moisture.
- Periodic maintenance to detect or avoid plugging of the ITS by roots.
- Thinning of the stand may be necessary.
- Herbaceous plant management and transition to woody overstory. Vigorous early growth of the understory may require some weed control around trees until they "escape" and grow above the understory. This is typical during the first year after planting.
- Tree death and windfall must be left on-site or removed as system self-sizes.
- Retirement of the irrigation system. It may be easiest to leave it in place and cease to operate it.

- Monitoring equipment should remain as long as it works and continues to support site management.

Capital Cost Estimate

Capital costs are provided for the passive and passive/active systems have been estimated on an order-of-magnitude basis. The information presented is based on the conceptual layouts of the proposed systems. Costs for certain system sub-components are provided on a per-acre basis. Actual pipe routes, pump requirements and system appurtenances have not been field proofed.

Passive System

The estimated total cost for the passive phytoremediation system is $366,000. A breakdown of system components is provided in Table A-1 (in Appendix A). As previously mentioned the passive system will have 18 acres of planted native cottonwood trees. Approximately 15 of the 18 acres will be subsurface irrigated. The trees will be planted as 9 to 12-foot rooted stock, which are augured into the soil to a depth of 6 feet. This deep planting will reduce the time to deep root-zone establishment. A total of 15,660 trees will be planted in the passive system at an estimated installation cost of $8 per tree.

Major components of the cost estimate are the combined conveyances ($39,600), the modular flow regulating tank ($22,000), field manifold ($14,000), submain system ($24,600), subsurface drip tubing ($25,000), control and monitoring instrumentation ($7,500) and trees ($125,300). The total cost on a per acre basis is $17,140. The per-acre infield irrigation application system cost is $8,660.

Actual pipe routes, appurtenances quantities, and costs may change in final design.

Passive/Active System

The estimated total cost for the passive/active phytoremediation system is $671,000. A breakdown of system components is provided in Table A-2. The passive/active system includes 46 active acres with the 18-acre passive system yielding 64 total acres. The location of the active system will have a large impact on active system conveyance costs. Currently the active system is proposed to be located south of the WWTP facility. The major differences in passive/active system componentry resulting in the increased cost over the strictly passive system are: the new 0.5 MG modular storage facility ($34,000), increased acreage (64 total acres), additional conveyance and subsurface irrigation tubing. The system cost on a per acre basis is $11,032 and the in-field irrigation application system cost is $7,406. Actual pipe routes, appurtenances quantities, and costs may change in final design.

Summary and Recommendation

The passive long-term vision RFETS and evolving technological and regulatory approaches to the SPP make definitive remediation design a challenge. The best approach appears to be artful combination of complementary technologies to achieve short-term regulatory targets and long-term site management goals.

Uptake within a passive phytoremediation will reduce nitrogen load within the SPP by about one-third of the mass currently recovered in the SPP. Denitrification within the root

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zone of this system is much harder to predict, but could remove 50 to 100 percent again of the amount taken up. This removal would be identical to that effected in the proposed denitrification trench, but would occur in bulk soil, fueled by the 14 tons of carbon contributed annually by the system's root system. The order-of-magnitude cost for the proposed, 18-acre passive system is $366,000.

Irrigation of the passive system with water from the ITS should be pilot tested on a small, carefully monitored plot. Uptake and transport of uranium in plant tissue should be quite limited, and the proposed method of subsurface drip irrigation further minimizes the risk of uranium bioavailability. However, neither the literature nor laboratory studies can provide the cost-effective certainty of an on-site trial.

Addition of an active phytoremediation system presupposes that uranium will be removed from the ITS water. Further, to minimize storage requirements, it is assumed (and recommended) that ITS trenches be capped with a vegetated cover that will greatly reduce infiltration and inflow of surface water. Once mixed with SPP water, this I&I must be stored, and that is costly.

The proposed active system would beneficially use 100 percent of the nitrogen load currently collected in the ITS. This would leave groundwater (and nitrate) not currently collected in the ITS to be dealt with by other component technologies, including the passive phytoremediation component. In this case, no SPP water would be used for irrigation within the SPP, an improvement over the passive-only system, since the established trees should have no problem meeting their need for nitrogen by uptake from groundwater. The order-of-magnitude cost of the proposed, 64-acre passive/active system is $671,000.

The size and shape of the passive and passive/active systems conform to criteria set by the overall remediation effort context. However, this context will certainly evolve. As it does, bear in mind that these systems are flexible; they can be enlarged, shrunk, and moved as needed, so long as they still conform to site management and plant growth requirements.

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Attachment A
Cost Tables

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Table A-1

Potential Phytoremediation and Land Application of Nitrogen Contaminated Groundwater at Rocky Flats, Colorado: Passive System Costs

The information presented below is based on a conceptual layout of the proposed system.
The pipe routes, pump requirements have not been field proofed.

Assumptions:

Size of Passive System

Passive System will cover NO3 plume area below the cutoff trenches.
(Measured from Figure 1 RFCA Groundwater Monitoring Wells, Selected VOC & Nitrate Plumes Third Quarter, 1996 Exceedances)

Area = 15 acres

Other Assumptions

Conveyance pipeline costs	$2	per diam-in per linear foot
Passive System Size	15	ac
Tree Spacing	10 by	5
Block Size	6	ac
Number of Manifolds	based on 1 manifold per 40 acre field	
Land Cost	not applicable	
Irrigation System	subsurface drip	
Filtration System	required	

Irrigation Requirement Calculations

Irrigation requirement	16	inches	
Irrigation season	5	months	
Set Time for ITS Application	2	hrs	
Estimated Irrigation Time for WWTP Water	4	hours	
Assumed irrigation flowrate requirement for passive system	72	gpm	0.16 cfs

Available Water Sources

Collected Groundwater Available	1,050,000	gallons	
Daily Groundwater Available	2877	gpd	0.004 cfs
WWTP Produced	200,000	gpd	0.31 cfs
Total Daily Known Source Available	202,877	gpd	0.31 cfs

Pipe Sizing and Pump Calcs

Maximum Sizing Case Where All Passive Site Irrigation Needs Must Be Met With WWTP Water

Assumes a 5 acre block size

Conveyance of WWTP to Passive	72 gpm	0.16 cfs	
Velocity in pipe	7 fps		
Conveyance of WWTP Diameter	6.46 inches	(say	6 inches)
Pipe Length	2000 ft		
Pipe Friction Losses	1.01 ft		
Elevation Gain	60 ft		
Pressure at Manifold[a]	92 ft	40 psi	
Total Head	153		
Pump Hp	3.51		
Conveyance pipe costs	$12 per lf		

Assume all GW could be used at Passive site

Do not know location of new storage tanks. Assume in same location as existing. Drain storage every other day.

Conveyance of GW storage to Passive Site[b]	2,877 gpd	0.053 cfs f(set time)	24 gpm
Velocity in pipe	7 fps		
Conveyance of GW Diameter	3.71 inches	say	4 inches
Pipe Length	1950 ft		
Pipe Friction Losses	0.92 ft		
Elevation Gain	20 ft		
Pressure at Manifold[a]	92 ft	40 psi	
Total Head	113		
Pump Hp	0.86		
Conveyance pipe costs	$8 per lf		

Storage Assumptions and Cost

Modular storage should have capacity 3 days of ITS Flow (10000 gal)

Costs provided below are for a containment storage tank

Storage Reservoir Cost	10000 gal	$6,700
Containment Storage Tank	12000 gal	$13,298
Subtotal - reservoir		$19,998
Fittings and Connections	10% of Subtotoal	$2,000
Total		$21,998

Capital Costs- Passive System

Item	Quantity	Unit	Unit Cost	Extended Cost
Site Preparation	18	ac	$650	$11,700
Pump Station WWTP	1	3 hp	$900	$900
Pump Station GW Storage flow	1	1 hp	$500	$500
Booster Pump	1	1 hp	$500	$500
Filtraton System	1	ea	$700	$700
Conveyance Pipeline- WWTP flow to Passive Site	2000	lf	$12	$24,000
Conveyance Pipeline - GW Storage to Passive Site	1950	lf	$8	$15,600
Modular ITS Storage Tank	1	ea	$21,998	$21,998
Manifold System	1	ea	$14,000	$14,000
Distribution and Submain System	15	ac	$500	$7,500
Drip Tubing (5x5 ft Emitter Spacing)	130896	lf	$0.188	$24,608
I&C/Monitoring	15	ac	$500	$7,500
Tree System (10' x 5' , 870 trees/ac)	15660	trees	$8.00	$125,280
Subtotal - Active				$254,786
Engineering Cost (15% of Subtotal)				$38,218
Project Cost				$293,004
Contingency (25% of Project Cost)				$73,251
Overall Capital Cost				$366,255

Summary:

Per acre total cost	$20,348
In-field Irrigation Application System Cost	$257,152
Per acre Infield Irrigation Application System Cost	$17,143

Notes:

[a]Assuming PC emitters wil be used

[b]Based on set time

Table A-2

Potential Phytoremediation and Land Application of Nitrogen Contaminated Groundwater at Rocky Flats, Colorado: Passive/Active System Costs

The information presented below is based on a conceptual layout of the proposed system.
The pipe routes, pump requirements have not been field proofed.

Assumptions:

Size of Passive System

Passive System will cover NO3 plume area below the cutoff trenches.
(Measured from Figure 1 RFCA Groundwater Monitoring Wells,
Selected VOC & Nitrate Plumes Third Quarter, 1996 Exceedances)

Area =	15	acres

Size of Active System

Active System will be based on the following:

Nitrate in groundwater	785	mg/L
Average Annual GW collected	1.05	MG
Total Nitrogen available in GW	6870	lb
Nitrogen uptake by plants	150	lb/ac
Area=	46	ac

Other Assumptions

Conveyance pipeline costs	$2	per diam-in per linear foot	
Passive System Size	15	ac	
Active System Size	46	ac	
Tree Spacing	10	by	5 feet
Block Size	6	ac	
Number of Manifolds	based on 1 manifold per 40 acre field		
Land Cost	not applicable		
Irrigation System	subsurface drip		
Filtration System	required		

Irrigation Requirement Calculations

Irrigation requirement	16	inches		
Irrigation season	5	months		
Set Time for ITS Application	2	hrs		
Estimated Irrigation Time for WWTP Water	4	hours		

Assumed irrigation flowrate requirement for passive system	72	gpm	0.16	cfs
Assumed irrigation flowrate requirement for active system[a]	36	gpm	0.08	cfs
Total irrigation requirement	109	gpm	0.24	cfs

Available Water Sources

Collected Groundwater Available	1,050,000	gallon		
Days in Growing/Irrigation Season	153	days	(May-Sept)	
Daily Groundwater Available	6863	gpd	0.011	cfs
WWTP Produced	200,000	gpd	0.31	cfs
Total Daily Known Source Available	206,863	gpd	0.32	cfs

Pipe Sizing and Pump Calcs

Maximum Sizing Case Where All Active Site Irrigation Needs Must Be Met With WWTP Water
Assumes a 5 acre block size

Conveyance of WWTP to Active	36	gpm	0.08	cfs	
Velocity in pipe	7	fps			
Conveyance of WWTP Diameter	4.57	inches say			6 inches
Pipe Length	1729	ft			
Pipe Friction Losses	0.24	ft			
Elevation Gain	40	ft			
Pressure at Manifold[b]	92	ft	40	psi	
Total Head	133		need small booster		
Pump Hp	1.52				
Conveyance pipe costs	$12	per lf			

Maximum Sizing Case Where All Passive Site Irrigation Needs Must Be Met With WWTP Water
Assumes a 5 acre block size

Conveyance of WWTP to Passive	72	gpm	0.16	cfs	
Velocity in pipe	7	fps			
Conveyance of WWTP Diameter	6.46	inches (say			6 inches)
Pipe Length	2000	ft			
Pipe Friction Losses	1.01	ft			
Elevation Gain	60	ft			
Pressure at Manifold[b]	92	ft	40	psi	
Total Head[c]	153	ft			
Pump Hp	3.51	Hp			
Conveyance pipe costs	$12	per lf			

Assume all GW could be used at Active site

Do not know location of new storage tanks. Assume in same location as existing. Drain storage every other day.

Conveyance of GW storage to Active[d]	6,863	gpd	0.127	cfs f(set time)	57 gpm
Velocity in pipe	7	fps			
Conveyance of GW Diameter	5.74	inches (say			6 inches)
Pipe Length	3350	ft			
Pipe Friction Losses	1.09	ft			
Elevation Gain	20	ft			
Pressure at Manifold[b]	92	ft	40	psi	
Total Head[c]	113	ft			
Pump Hp	2.05	Hp			
Conveyance pipe costs	$12	per lf			

Storage Reservoir Assumptions and Cost

Storage reservoir should have capacity to store off season flows from ITS

Costs provided below are for a lined reservoir, 10 feet deep (approx .5 acre in size)

Storage Reservoir Cost	0.6 MG	$30,000	$18,000
Subtotal - reservoir			$18,000
Engineering Cost (15% of Subtotal)			$2,700
Project Cost			$20,700
Contingency (25% of Project Cost)			$5,175
Overall Capital Cost - storage reservoir			$25,875

Capital Costs- Active+Passive Systems

Item	Quantity	Unit	Unit Cost	Extended Cost
Site Preparation	61	ac	$650	$39,520
Pump Station WWTP	1	3 hp	$1,000	$1,000
Pump Station GW Storage flow	1	2 hp	$800	$800
Booster Pump	1	1 hp	$500	$500
Filtraton System	1	ea	$700	$700
Conveyance Pipeline- WWTP flow to Active Site	1729	lf	$12	$20,748
Conveyance Pipeline- WWTP flow to Passive Site	2000	lf	$12	$24,000
Conveyance Pipeline - GW Storage to Active Site	3350	lf	$12	$40,200
New 0.6 MG Storage Facility	1	ea	$25,875	$25,875
Manifold System	3	ea	$14,000	$42,000
Distribution and Submain System	61	ac	$500	$30,400
Drip Tubing (5x5 ft Emitter Spacing)	550124	lf	$0.188	$103,423
I&C/Monitoring	61	ac	$200	$12,160
Tree System (10' x 5' , 870 trees/ac)	15660	trees	$8.00	$125,280
Subtotal - Active				$466,607
Engineering Cost (15% of Subtotal)				$69,991
Project Cost				$536,598
Contingency (25% of Project Cost)				$134,149
Overall Capital Cost				$670,747

Summary:

Per acre total cost	$11,032
In-field Irrigation Application System Cost	$450,316
Per acre Infield Irrigation Application System Cost	$7,406

Notes:

[a]Flow = 1/2 required flow for tree survival

[b]Assuming PC emitters wil be used

[c]Need small booster

[d]Based on set time

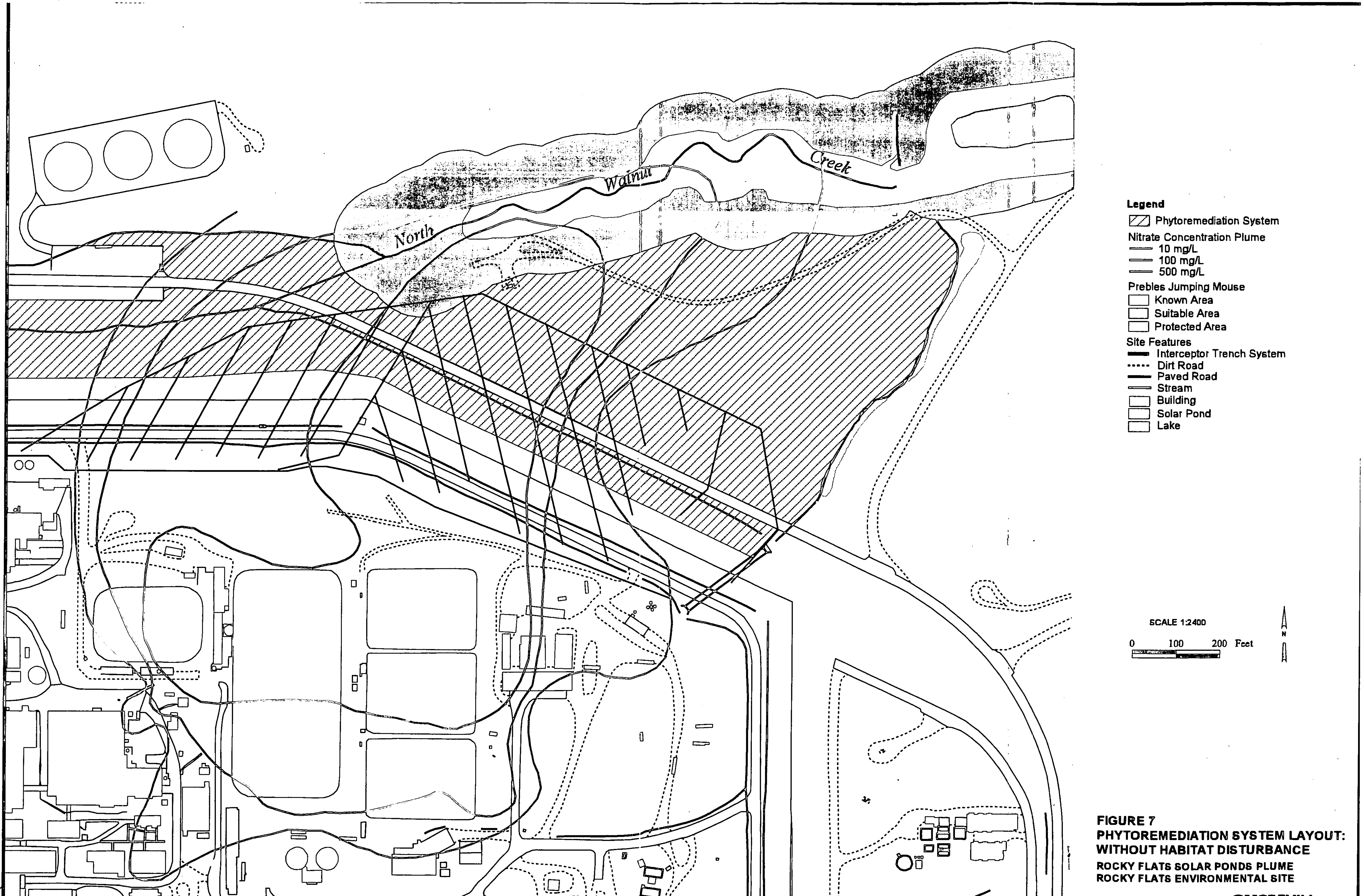

FIGURE 7
PHYTOREMEDIATION SYSTEM LAYOUT: WITHOUT HABITAT DISTURBANCE
ROCKY FLATS SOLAR PONDS PLUME
ROCKY FLATS ENVIRONMENTAL SITE

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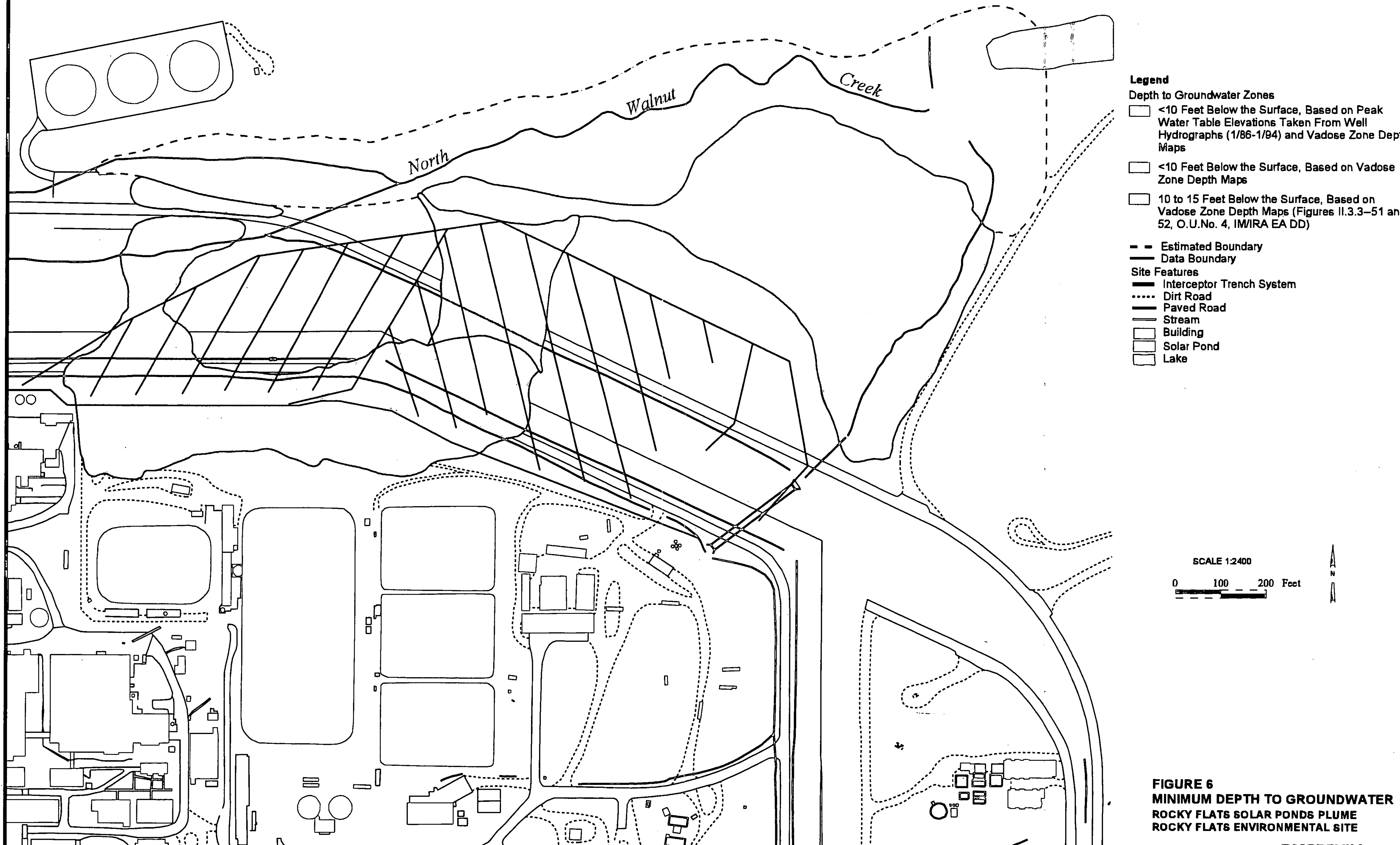

FIGURE 6
MINIMUM DEPTH TO GROUNDWATER
ROCKY FLATS SOLAR PONDS PLUME
ROCKY FLATS ENVIRONMENTAL SITE

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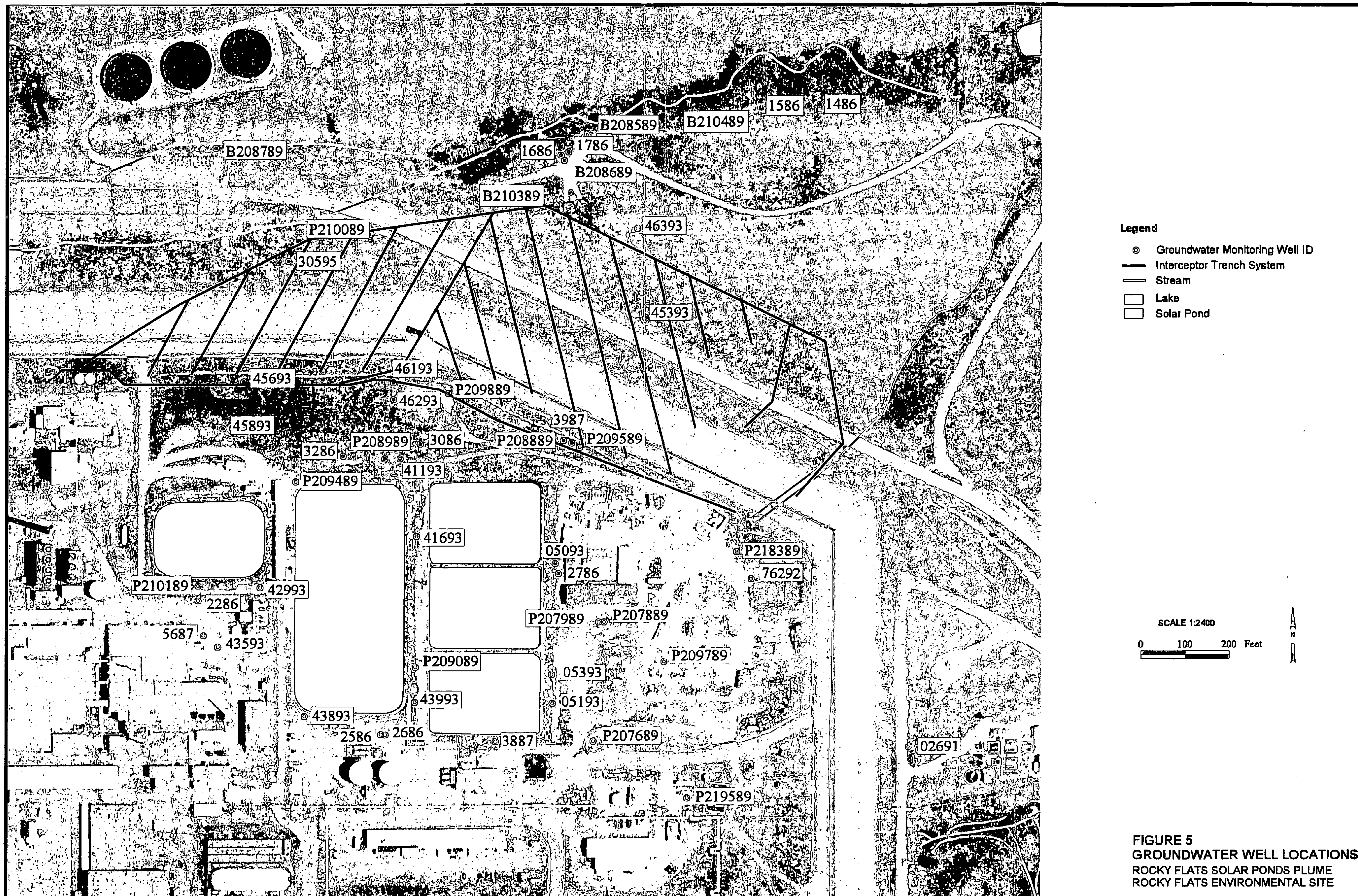

FIGURE 5
GROUNDWATER WELL LOCATIONS
ROCKY FLATS SOLAR PONDS PLUME
ROCKY FLATS ENVIRONMENTAL SITE

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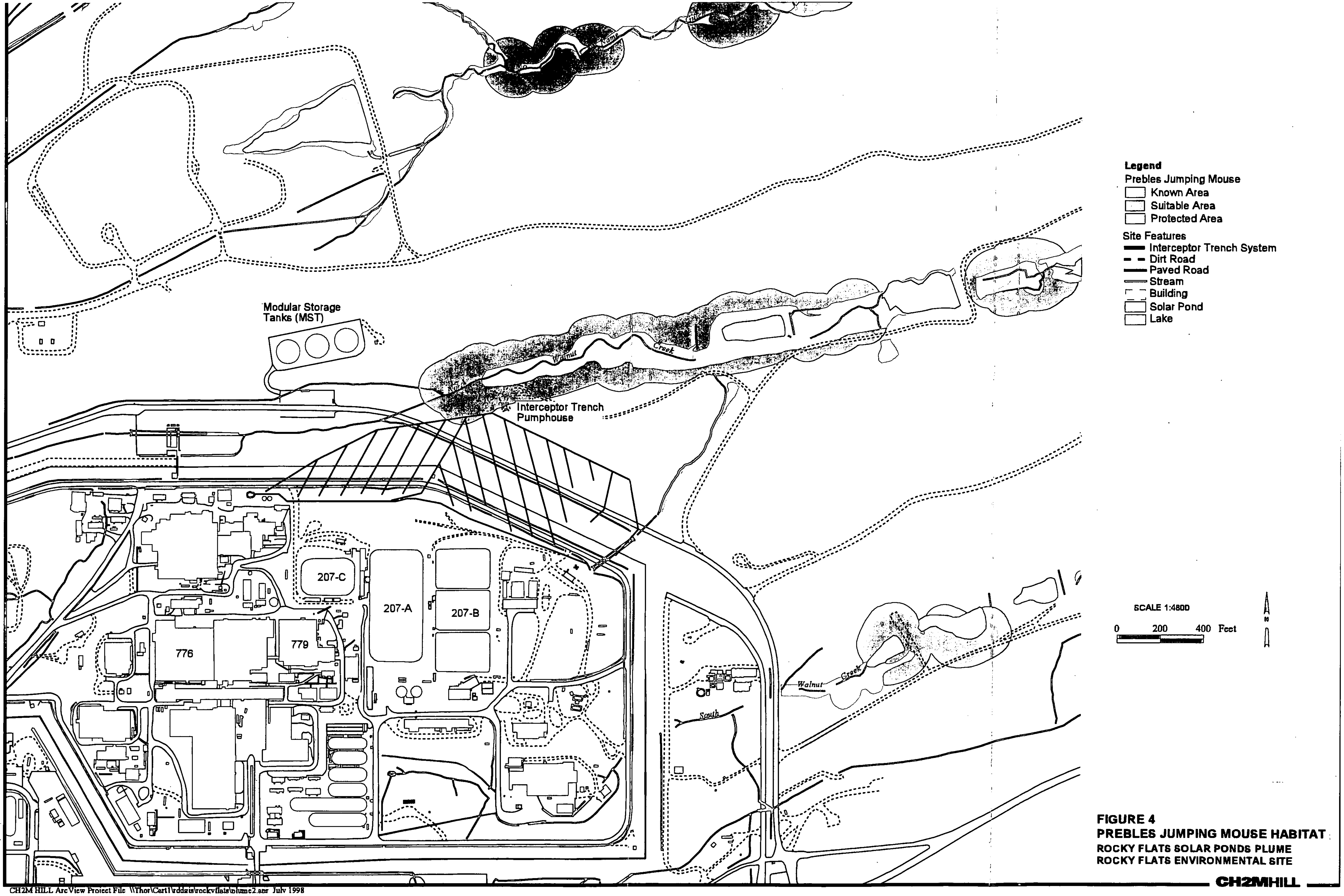

FIGURE 4
PREBLES JUMPING MOUSE HABITAT
ROCKY FLATS SOLAR PONDS PLUME
ROCKY FLATS ENVIRONMENTAL SITE

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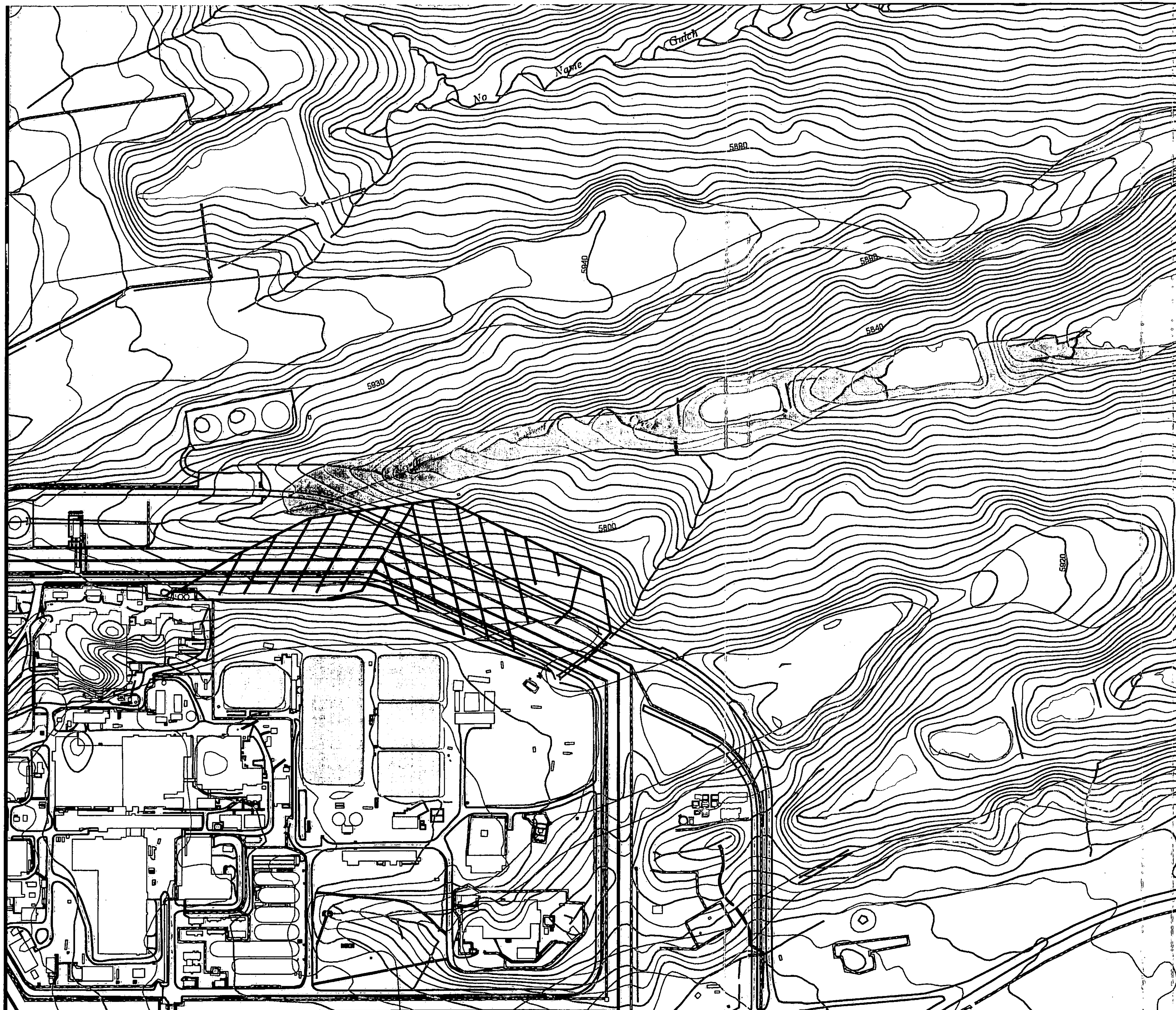

Legend

Soils

- Denver-Kutch-Midway clay loams, 9 to 25 percent slopes
- Flatirons very cobbly sandy loam, 0 to 3 percent slopes
- Haverson loam, 0 to 3 percent slopes
- Nederland very cobbly sandy loam, 15 to 50 percent slopes
- Valmont clay loam, 0 to 3 percent slopes

Site Features

- 5 Foot Contours
- Fence
- Interceptor Trench System
- Paved Road
- Stream
- Solar Pond
- Lake
- Building

1:4800

0 200 400 Feet

N

FIGURE 3
SOILS AND TOPOGRAPHY
ROCKY FLATS SOLAR PONDS PLUME
ROCKY FLATS ENVIRONMENTAL SITE

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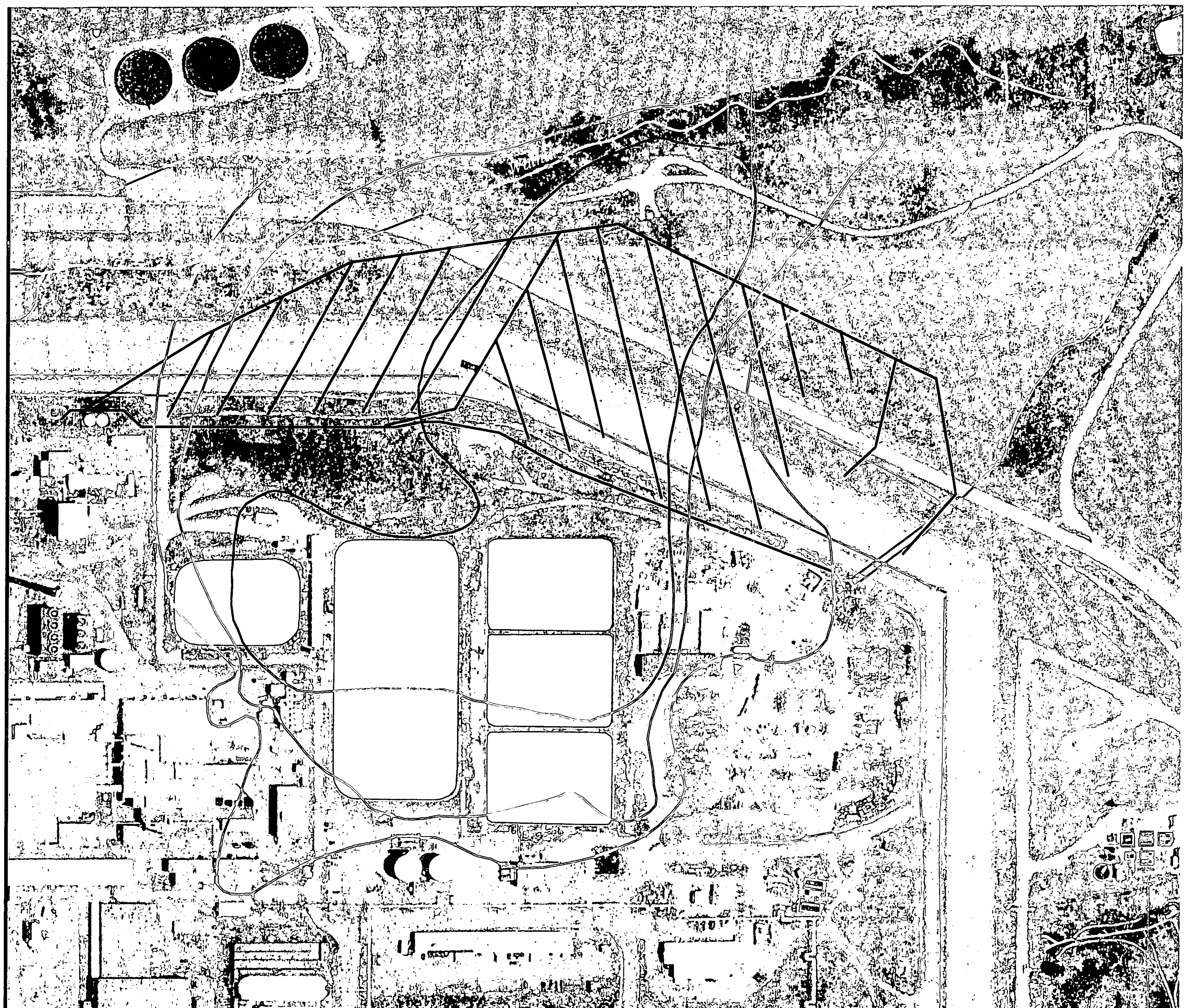

Legend
Nitrate Concentration Plume
10 mg/L
100 mg/L
500 mg/L
Site Features
Interceptor Trench System
Stream
Lake
Solar Pond

SCALE 1:2400
0 100 200 Feet

FIGURE 2
SOLAR PONDS NITROGEN PLUME
ROCKY FLATS SOLAR PONDS PLUME
ROCKY FLATS ENVIRONMENTAL SITE

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